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Design & Analysis Of Wind Lens

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ABSTRACT

A new and efficient aerodynamic design method has been developed for the new type of wind turbine called "wind-lens turbine". The wind-lens turbine has a diffuser with brim called "wind-lens", by which the wind concentration on the turbine rotor and the significant enhancement of the turbine output can be achieved. The present design method is based on a genetic algorithm (GA) and a quasi-three-dimensional design of turbine rotor. The quasi-three-dimensional design consists of two parts: meridional viscous flow calculation and two-dimensional blade element design. In the meridional viscous flow calculation, an axisymmetric viscous flow is numerically analysed on a meridional plane to determine the wind flow rate through the wind-lens and the span wise distribution of the rotor inlet flow. In the two-dimensional rotor blade element design, the turbine rotor blade profile is determined by a one-dimensional through flow modelling for the wind-lens turbine and a two-dimensional blade element theory based on the momentum theorem of the ducted turbine.

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I. INTRODUCTION

In current years, wind energy has become one of the most cost-effective renewable energy technologies. Today, electricity generating wind turbines is proven and tested technology, and provide a secure and sustainable energy supply.

The technological development of recent years, bringing more efficient and more reliable wind turbines, is making wind power more cost-effective. In general, the specific energy costs per annual kWh decrease with the size of the turbine not withstanding existing supply difficulties. Wind power generation is proportional to the wind speed cubed. If we can increase the wind speed with some mechanism by utilizing the fluid dynamic nature around a structure, namely if we can capture and concentrate the wind energy locally, the output power of a wind turbine can be increased.

N. Manikandan and B. Stalin [1] have studied about the design of aerofoil section in the wind turbine. They have researched the design of blades with the help of softwares like Pro-E and Hyper mesh. They have considered the NACA 63-215 aerofoil profile for the proper analysis of the wind turbine.

Yuji Ohya, etc. have studied about the wind lens, rather than the wind turbine. They have researched about the design of brim (lens). They found out that the lensed turbine has shown the potential to increase the power output for any given diameter of the turbine compared to a conventional wind turbine. This was because of a low-pressure region due to a strong vortex formation behind the broad brim draws mass flow to the wind turbine inside the diffuser . With respect to the above information we have designed a prototype considering all the parameters acting on it to verify and conquer the Betz law and are trying to make further modifications.

II. PROBLEM STATEMENT

Most of the resources used by mankind today are in a state of depletion because they are non renewable and the use is on a very high scale. Various renewable energy techniques have been developed since mankind has encountered this problem. Wind energy is one of the free sources of energy which is recently being used on a large scale because of the many advantages it has. At the same time windmill also has some disadvantages of its own. Here rises the need to improve effectiveness and new techniques to minimize the disadvantages and help capture and concentrate the wind energy locally such that the output power of a wind turbine can be increased substantially.

III. IMPORTANT PARAMETERS

Selecting number of blades – Getting the exact number of blades for the operation is of greater importance to the efficiency that we get from the turbine. There are different theories that help us understand the exact number of blades that we might need to suit the particular design.

Setting the output power – Based on the output requirements and applications taken into considerations the output power is selected. It is generally assumed comparatively higher than the requirements due to the losses.

Selection of material of each part – Material of each part should be selecting based on the strength and capacity. Material is one of the most important factors that affect the cost; hence it must be taken care of.

Wind velocity – The wind velocity for a particular region is given by the IMD department.

Rotor Diameter – We know the power torque and angular velocity relationship. Using this relationship along with Betz law and mechanical and electrical efficiency, rotor diameter is calculated. This diameter directly leads to the tower height.

IV. WORKING PRINCIPLE

Betz's law indicates the maximum power that can be extracted from the wind, independent of the design of a wind turbine in open flow. It was stated, by the German physicist Albert Betz. The law is derived from the principles of conservation of mass and momentum of the air stream flowing through an idealized "actuator disk" that extracts energy from the wind stream. According to Betz's law, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind. The factor 16/27 (0.593) is known as Betz's coefficient. Practical wind turbines achieve at peak 74% to 81% of the Betz limit.[2]

The Betz limit is based on an open disk actuator. If a diffuser is used to collect additional wind flow and direct it through the turbine, more energy can be extracted, but the limit still applies to the cross-section of the entire structure.
Betz' Law applies to all Newtonian fluids. Consider that if all of the energy coming from wind movement through a turbine was extracted as useful energy the wind speed afterwards would drop to zero. If the wind stopped moving at the exit of the turbine, then no more fresh wind could get in -it would be blocked. In order to keeps the wind moving through the turbine there has to be some wind movement, however small, on the other side with a wind speed greater than zero. Betz' law shows that as air flows through a certain area, and when it slows from losing energy to extraction from a turbine, it must spread out to a wider area. As a result, geometry limits any turbine efficiency to 59.3%.

V. DESIGN OF WIND TURBINE

Wind turbine: Designing a wind turbine and wind lens is based on the aerodynamics of the blades and vortex principle. Designing the blades is an intricate form of engineering wherein a lot of factors are considered simultaneously in order to get the best output of the renewable source of energy. The main factors for consideration are as follows;

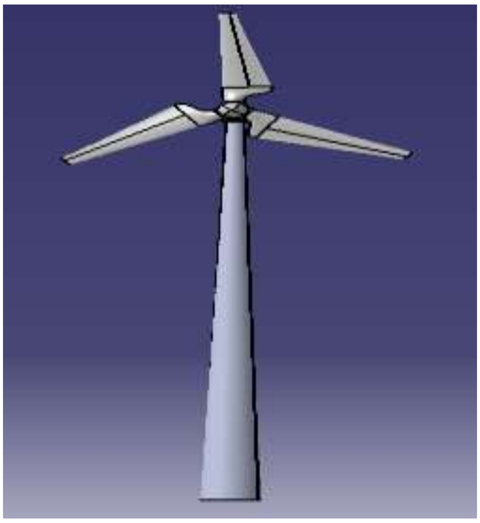


Fig. 1 Conventional Wind Turbine (CAD model)

Number of blades: Two blade wind turbine has comparative lower efficiency and is not suitable for the wind conditions for the respective region. Also, Rotor efficiency does increase very slightly if four blades are used, rather than three, but the rotor weight would increase and the rotational speed at which peak power would be delivered would drop. That, in turn, would increase the rotor torque necessitating a thicker shaft and the slower speed would mean a more expensive gearbox, as the gear ratio would increase. Slow-turning multi blade machines are better suited to applications such as water pumping than to electricity generation. Thus we use Three Blade wind turbine.

Aerofoil Profile: A number of wind turbine aerofoil's are available in different series suited for different application. NACA-6 series has the following advantage,

1. High maximum lift coefficient
2. Very low drag over a small range of operating conditions
3. Optimized for high speed

For our advantage, we have chosen the NACA 63-215 series. The profile of the same can be seen in the image below

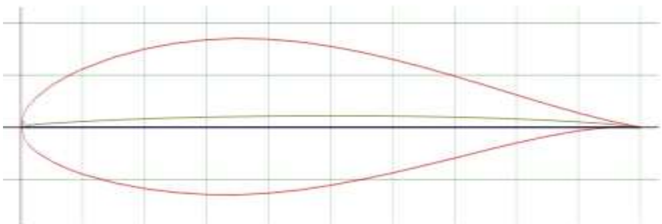


Fig. 2 NACA 63-215 Profile[3]

VI. CONCEPTS

Aerofoil: An aerofoil is the shape of a wind blade (of a propeller, rotor, of turbine). An aerofoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. Subsonic flight aerofoil have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with asymmetric curvature of upper and lower surfaces. The lift on an aerofoil is primarily the result of its angle of attack and shape. When oriented at a suitable angle, the aerofoil deflects the oncoming air (for fixed-wing aircraft, a downward force), resulting in a force on the aerofoil in the direction opposite to the deflection. This force is known as aerodynamic force and can be resolved into two components: lift and drag. Most foil shapes require a positive angle of attack to generate lift, but cambered aerofoils can generate lift at zero angle of attack. This "turning" of the air in the vicinity of the aerofoil creates curved streamlines, resulting in lower pressure on one side and higher pressure on the other.

Angle of Attack: The angle of attack is the angle between the chord line of an aerofoil and the oncoming air. A symmetrical aerofoil will generate zero lift at zero angle of attack. But as the angle of attack increases, the air is deflected through a larger angle and the vertical component of the airstream velocity increases, resulting in more lift. For small angles a symmetrical aerofoil will generate a lift force roughly proportional to the angle of attack. As the angle of attack grows larger, the lift reaches a maximum at some angle; increasing the angle of attack beyond this critical angle of attack causes the upper-surface flow to separate from the wing; there is less deflection downward so the aerofoil generates less lift. The aerofoil is said to be stalled.

Lift and Drag: Lift, or downforce is the force generated perpendicular to the direction of travel for an object moving through a fluid. The same effect occurs when a fluid moves over a stationary object, such as, in this case, an air foil in the wind turbine. Drag is an unavoidable consequence of an object moving through a fluid. Drag is the force generated parallel and in opposition to the direction of travel for an object moving through a fluid.

ANSYS Verification

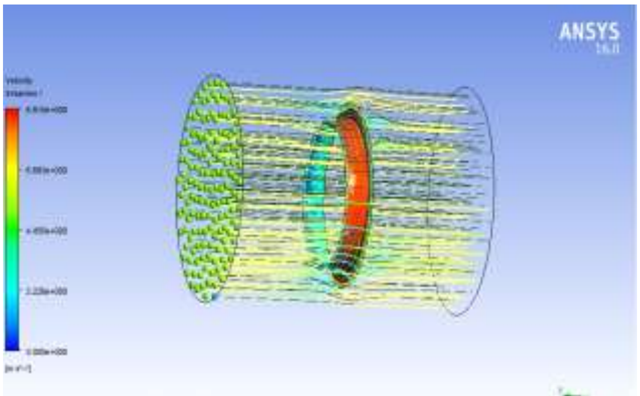


Fig. 3 ANSYS (At Starting Point)

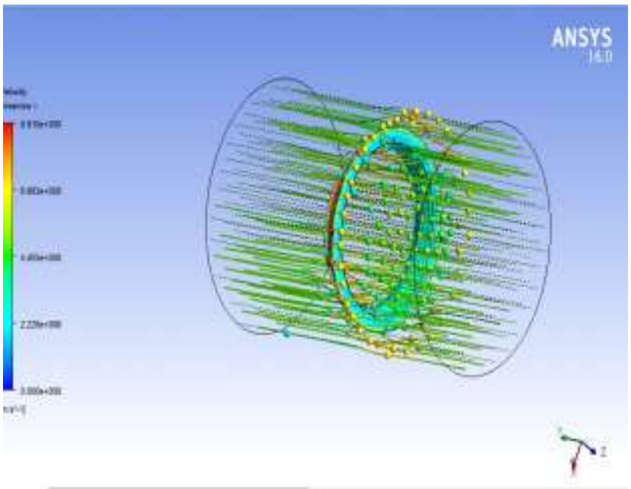
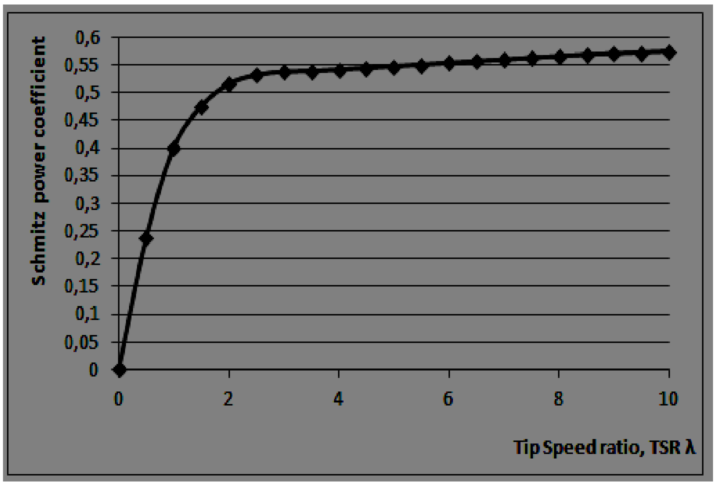


Fig. 4 ANSYS (At the Centre)

As shown in the images above, we can clearly see that there is an increase in the air velocity right when the air passes the brim section. To be more precise, the air velocity starts at 4.5 m/s but by the time it reaches the brim, it shoots up to almost 7-8 m/s. And that's the motive of designing the brim.



VII.DESIGN CALCULATIONS

The design of the wind turbine is for an output power of 50 watt.

Thus **P = 50 Watt**.

DIAMETER OF ROTOR BLADES

$$Power = \left(\frac{(\pi \times \rho \times D^2 \times V_\infty^3 \times C_p \times \eta_m \times \eta_e)}{8}\right) \ldots(1)$$

Fig. 5 Tip speed ratio

Where P= Power Output of the Wind Mill.

P = Density Of air (kg/m³).

D = Rotor Diameter of the wind mill.

$V\infty$ = Velocity of Air (Pune) (m/sec).

= Betz law coefficient.

= Mechanical Efficiency.

= Electrical Efficiency.

Taking Maxing Possible Efficiency

= 0.9

= 0.95

= 0.593 … (From Betz Law)

Desired Output P= 50 Watt.

Substituting all the above values into equation (1).

Therefore,

$$50 = \left(\frac{1.22 \times \pi \times D^2 \times 5^3 \times 0.95 \times 0.9 \times 0.593}{8}\right)$$

$$D^2 = \left(\frac{(50 \times 8)}{(1.22 \times \pi \times 5^3 \times 0.95 \times 0.9 \times 0.593)}\right)$$

$$D = 1.2832m$$

$$R = \frac{D}{2} = 1.2832/2$$

$$R = 0.6416m$$

HEIGHT OF TOWER

Considering the safety, cost and wind velocity, the height of the tower is generally considered twice the diameter

.$H = 2\times D$

$H = 2\times 1.2832$

$\boldsymbol{H = 2.5664m}$

TIP SPEED RATIO

From the above graph,

Tip Speed Ratio (TSR) = 5 (Design is for 3 blades)

But we know that,

Tip Speed Ratio (TSR)= $\left(\frac{2\times\pi\times R\times N}{V_\infty}\right)$

Where,

R = rotor radius of wind mill *(m).*

N = speed of rotor (*rpm*).

V_∞ =Velocity of air (Pune) *(m/sec).*

Thus,

$$N = \left(\frac{TSR\times V_\infty}{2\times\pi\times R}\right)$$

$$N = \left(\frac{5\times 5}{2\times\pi\times 0.6416}\right)$$

$N = 6.201rps.$

$I = \beta + \alpha$

$\alpha = I - \beta$

$\alpha = 11.30-4.5$

$\boldsymbol{\alpha = 6.8099^o}$

Hence, the optimum angle of attack is **6.8099°**.

Also similarly angle of attack at all other points are,

For Point 1,

$$U = 2 \times \pi \times R_1$$

$$U = 2 \times \pi \times 0.1604 \times 6.201$$

$\boldsymbol{U = 6.2495\ m/s}$

$$I = \tan^{-1}\left(\frac{V_\infty}{U}\right)$$

$$I = \tan^{-1}\left(\frac{5}{6.2495}\right)$$

$\boldsymbol{I_1 = 38.66^o}$

$\alpha = I - \beta$

$\alpha = 38.66-4.5$

$\boldsymbol{\alpha_1 = 34.1620^o}$

For Point 2,

$$U = 2\pi \times R_1$$

$$U = 2\pi \times 0.3208 \times 6.201$$

$U = 12.5\ m/s$

$$I = \tan^{-1}\frac{V_\infty}{U}$$

$$I = \tan^{-1}\frac{5}{12.5}$$

$\boldsymbol{I_2 = 21.801^o}$

$\alpha = I - \beta$

$\alpha = 21.801-4.5$

$\boldsymbol{\alpha_2 = 17.3014^o}$

For Point 3,

$$U = 2\pi \times R_1 \times N$$

$$U = 2\pi \times 0.4812 \times 6.201$$

Fig. 6 Blade division

$U = 18.7485\ m/s$

$$= I \tan^{-1}\frac{V_\infty}{U}$$

$$= I \tan^{-1}\frac{5}{18.748}$$

$\boldsymbol{I_3 = 14.9325^o}$

$\alpha = I - \beta$

$\alpha = 14.9325-4.5$

$\boldsymbol{\alpha_3 = 10.4325^o}$

Dividing the blade into a number of section,

$R_1 = 0.1604m$

$R_2 = 0.3208m$

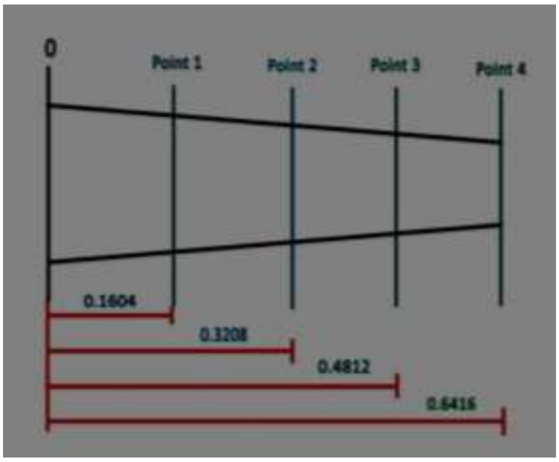
$R_3 = 0.4812m$

$R_4 = 0.6416m$

Applying the Tip speed ratio formula to get the local tip speed ratio at the respective points.

$$TSR = \left(\frac{(2\pi \times R \times N)}{V_\infty}\right)$$

Where,



V_R = local tip speed ratio.

$$\lambda_1 = \left(\frac{(2\pi \times R_1 \times N)}{V_\infty}\right)$$

$$\lambda_1 = \left(\frac{(2\pi \times 0.1604 \times 6.201)}{5}\right)$$

$\boldsymbol{\lambda_1 = 1.249}$

$$\lambda_2 = \left(\frac{(2\pi \times R_2 \times N)}{V_\infty}\right)$$

$$\lambda_2 = \left(\frac{(2\pi \times 0.3208 \times 6.201)}{5}\right)$$

$\boldsymbol{\lambda_2 = 2.4998}$

$$\lambda_3 = \left(\frac{(2\pi \times R_3 \times N)}{V_\infty}\right)$$

$$\lambda_3 = \left(\frac{(2\pi \times 0.4812 \times 6.201)}{5}\right)$$

$\boldsymbol{\lambda_3 = 3.7497}$

$$\lambda_4 = \left(\frac{(2\pi \times R_4 \times N)}{V_\infty}\right)$$

$$\lambda_4 = \left(\frac{(2\pi \times 0.6416 \times 6.201)}{5}\right)$$

$\boldsymbol{\lambda_4 = 5}$

ANGLE OF TWISTS

$$\Psi = \left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{\lambda_R}\right)$$

Where,

Ψ = angle of twists (º).

λ_R = local tip speed ratio.

$$\Psi = 1\left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{\lambda_{R_1}}\right)$$

$$\Psi = 1\left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{1.2949}\right)$$

$\boldsymbol{\Psi 1 = 25.788^\circ}$

$$\Psi 2 \left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{\lambda_{R_2}}\right)$$

$$\Psi 2 = \left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{2.4998}\right)$$

$\boldsymbol{\Psi 2 = 14.5353^\circ}$

$$\Psi 3 = \left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{\lambda_{R_3}}\right)$$

$$\Psi 3 = \left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{3.4797}\right)$$

$\boldsymbol{\Psi 3 = 9.9550^\circ}$

$$\Psi 4 = \left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{\lambda_{R_4}}\right)$$

$$\Psi 4 = \left(\frac{2}{3}\right)\tan^{-1}\left(\frac{1}{5}\right)$$

$\boldsymbol{\Psi 4 = 7.5399^\circ}$

COEFFICIENT OF LIFT AND DRAG

Cl = Coefficient of lift.

Cd = Coefficient of drag.

Re = Reynold's Number.

Reynold's number: In fluid Mechanics, The Reynolds's Number (Re) is a dimensionless quantity that is used to help predict similar flow patterns in different fluid flow situations.

Mach number (M): In fluid Dynamics, the Mach number (M) is a dimensionless quantity representing the ratio of flow velocity past a boundary to the local speed of sound. C is the speed of sound in the medium.

For *Re* = 200000

Mach number = 0

NCIRT = 9

Max *Cl /Cd* = 65.

NACA 63-215 AIRFOIL

Mach = 0.000 *Re* = 0.200 e 6

N_{crit} = 9.000

Alpha	CL	CD	CDp
6.750	0.8499	0.01323	0.00765
7.000	0.8820	0.01347	0.00782

Thus from the above Table Interpolating,

For $\alpha = 6.8099^{o}$

(7.0000 – 6.7500) / (7.000 – 6.8099) = (0.01347- 0.01323) / (0.01347 – Cl1)

Cl = 0.1560m

Cd = 0.1560m

CHORD LENGHTS

$$C = \frac{(8\pi \times R)(1-\cos\Psi)}{(B \times Cl)}$$

Where,

C = Chord Length (m).

Cl = coefficient of lift.

R = Radius of blade (m).

B = No. of Blades.

Ψ = Twist Angle (º).

Thus,

$$C_{1} = \frac{(8\pi \times 0.1604)(1-\cos 25.788)}{(3 \times 0.8575)}$$

$\boldsymbol{C_1 = 0.1560m}$

$$C_{2} = \frac{(8\pi \times 0.3208)(1-\cos 14.5353)}{(3 \times 0.8575)}$$

$\boldsymbol{C_2 = 0.10029m}$

$$C_{3} = \frac{(8\pi \times 0.4812)(1-9.9550)}{(3 \times 0.8575)}$$

$\boldsymbol{C_3 = 0.0706m}$

$$C_{4} \frac{(8\pi \times 0.6416)(1-\cos 7.5359)}{(3 \times 0.8575)}$$

$\boldsymbol{C_4 = 0.05411m}$

LIFT AND DRAG FORCES.

Calculating blade area from the CAD Model

Blade area = $\boldsymbol{A_b = 0.11m^2}$

Thus at optimum angle of attack the forces are,

LIFT FORCE

$$FL = \frac{(Cl \times \rho \times V_2 \times A_b)}{2}$$

Where

FL = lift Force (*N*)

P = Density of air (kg/m^3)

A_b = Blade area (m^2)

Cl = Coefficient of lift.

Hence,

$$FL = \frac{(0.8575 \times 1.22 \times 52 \times 0.11)}{2}$$

FL = 1.4384 N

DRAG FORCE

$$FD = \frac{(Cd \times \rho \times V_2 \times A_b)}{2}$$

FD = Drag Force (N)

P = Density of air (kg/m3)

A_b = Blade area (m2)

Cd = Coefficient of drag.

Hence,

$$FD = \frac{(0.01323 \times 1.22 \times 52 \times 0.11)}{2}$$

FD = 0.022 NN = 372.0891rpm.

Calculating the Area of Rotor,

$$A = (\pi \times D^2)$$

Where,

A = rotor blade area *(m^2).*

D = diameter of rotor *(m).*

$A = (\pi \times .2832^2)/4$

$\boldsymbol{A = 1.2932m^2}$

Material Used

Component	Material used	Material properties
Hub	Aluminium	Light weight
Blades	Deodar wood	Alternative for carbon fiber,Smooth finish
Slide rod & guideways	en8	Harder than MS,Slides easily
Frame	Mildsteel	High surface hardness
Brim	Mildsteel	High Toughness

VIII. CONCLUSION

It is possible for us to consider that the blade rpm has been increased due to the air velocity increment which is caused by the design of the brim structure. As the design of the blades was done in accordance with the NACA 6-Series, (63-215) the design of brim structure was made with respect to the blade design and it is evident that due to addition of the brim the velocity of air is increased which in turn had a positive impact on the rpm of the blades.
The verification of the brim design in shown by the increase in blade rpm which can be verified by the ANSYS model of the brim created.

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